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THE CHANNEL AERATION PROCESS AT GLENWOOD, MINNESOTA-A TWO YEAR STUDY

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Minnesota University
Saint Paul, Minnesota

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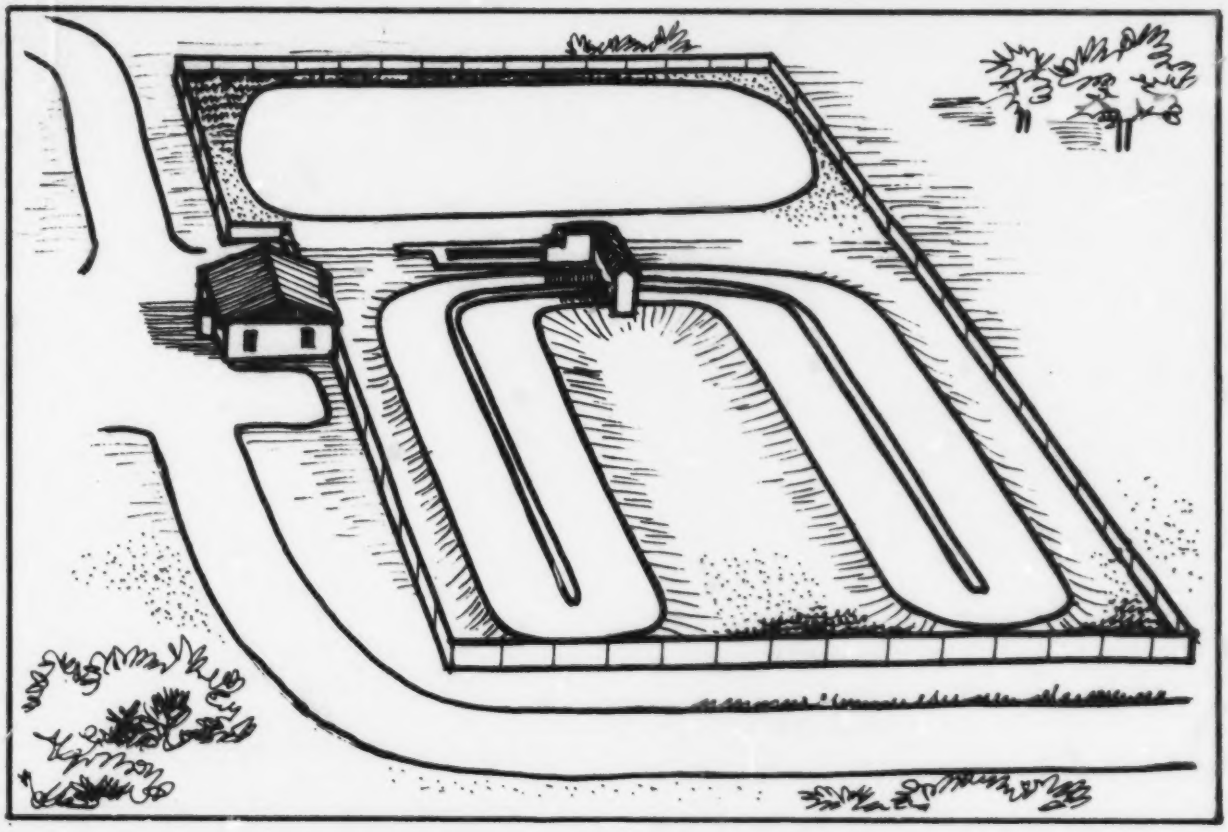

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GLENWOOD, MINNESOTA

SEWAGE TREATMENT PLANT

A REPORT

ON

THE CHANNEL AERATION PROCESS AT GLENWOOD MINNESOTA

A TWO YEAR STUDY

BY

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This study was made possible by a research grant from the Water Pollution Control Administration, Department of Interior, Washington, D.C.

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THE INTRODUCTION

The City of Glenwood, Minnesota was chosen as a suitable site for a channel aeration demonstration plant; a treatment method developed at the research institute for public health engineering - The Hague Netherlands, by Dr. A. Pasveer, chemist-bacteriologist. This was preceded by some laboratory studies carried out at the University of Illinois which indicated that the channel aeration process could remove from the sewage significant quantities of plant nutrients such as nitrogen and phosphate. Glenwood was chosen as a site for a demonstration plant for the following reasons:

1. It discharged its sewage effluent into a lake - (Lake Minnewaska) and this was the only organized community discharging sewage effluent into this lake. In recent years the lake was becoming more and more overgrown by algae and the citizens in Glenwood and others living near became concerned about the future use of the lake for fishing and recreation. The sewage treatment plant being used at Glenwood at this time was an old trickling filter plant with an anaerobic digester. The effluent was discharged into a small creek that emptied into the lake after a flow of only about a quarter of a mile. The treatment plant was too small for the community and as a result, very poor results were being obtained.

2. The algae growth in the lake was becoming progressively worse each year, particularly in that portion of the lake nearest the inlet of the creek that carried the effluent from the sewage treatment plant. It was therefore felt that if the channel aeration process was better suited for the removal of plant nutrients than a trickling filter plant perhaps this might be an excellent place to demonstrate the value of such a process.

3. The community was concerned about the preservation of the lake and therefore were very receptive to try this new type of treatment.

The City of Glenwood is located in west central Minnesota about 125 miles northwest of Minneapolis and is situated on the northeast shore of Lake Minnewaska. The lake is approximately 10 miles long and 3 miles at its widest point and extends southeast from the city of Glenwood. Lake Minnewaska has been noted for its beauty and excellent fishing and as a result has been an attraction for tourists that has had an important impact on the economy of the city. This is exemplified by the "Glenwood Waterama," an annual summer celebration centered around

water recreation activities. The plant at Glenwood was designed for a population of 2500 with added allowance for some industrial waste sufficient to increase the population equivalent to 4200. Most of the homes in Glenwood are connected to city sewers but there is also a considerable number of people living around the lake either in permanent homes or summer cottages and in most cases, these homes and cottages are not connected to a sewer. Instead they are served by septic tanks and the effluent from these are generally discharged into the lake or seep through the ground into the lake.

The old sewage treatment plant at Glenwood was heavily overloaded for a number of years and as a result the degree of purification obtained was very poor - less than 50%.

After the city had decided to proceed with the construction of the new sewage treatment plant, they engaged engineers who proceeded to design a channel aeration process. At the same time, arrangements were made to apply for a federal grant from funds allocated to the State for that purpose. Dr. Bauer of the State Board of Health and Dr. H. O. Halvorson, formerly director of the School of Sciences at the University of Illinois made applications for a research grant to assist in the equipment of a laboratory and to finance the collection of data for a period of four years. The following is a report of the results that were obtained from these studies:

DESCRIPTION OF THE PLANT

The channel aeration process that was constructed at Glenwood, Minnesota consists of the following units:

1. A laboratory building and control house.
2. An aeration channel equipped with the necessary aeration and propulsion devices.
3. A final settling tank.
4. Weir boxes and automatic sampling equipment for the raw sewage, and the effluent.
5. An auxilliary stabilization pond.

The laboratory and control house is a single story building above ground but has two basements. The sub-

basement is divided into two parts; a dry and a wet well and as the sewage enters the wet well, it passes through first a grit removal mechanism and a bar screen and through a Parshall flume that is equipped with a level device that records the flow on an integrated flow meter located in the laboratory. The solids collected by the bar screen are brought to the ground level and can either be ground and returned to the sewage or can be removed and hauled away. In normal operation, the practice has been to remove these solids and haul them to the city dump. The grit that is removed from the grit removal mechanism is brought up by buckets to the surface and is dumped into small containers that are hauled to the dump once or twice a week. In the dry well compartment of the sub-basement are located three raw sewage pumps each having a capacity of 150 gallons a minute. These are activated by a float in the wet well. On the first basement floor of the dry well is located the return sludge pump and additional space is available for storage. The first floor of the control house contains a laboratory that is about 20 x 30 feet and is equipped with suitable chemical benches and other fixed equipment necessary for the control work that is carried out in this building. The aeration channel is a double horse shoe channel and each branch is 15 feet wide at the water surface, 12½ feet wide at the bottom and a water depth of 3 feet. The cross section is 46½ square feet and the length 1250 feet with a volume capacity of 59,000 cu. ft or approximately 440,000 gallons.

Aeration and propulsion is usually accomplished by means of four cage rotors each 6 feet long, 70 inches in diameter and are operated usually at 75 rpm. The paddles on these cage rotors dip into the water from 3 to 9 inches depending on the level of water maintained in the aeration channel. Two of these cage rotors are operated by one 10 horse motor so that in all there are two 10 horse motors operating the cage rotors that serve to provide air and motion to the liquid. After the first two years of study it was decided that we could obtain better removal of nitrogen from the sewage if we had independent control of aeration and propulsion. There were times, in order not to introduce too much oxygen (particularly in cold weather), when we had to lower the liquid in the channel to the point where the paddles on the cage rotors immersed in the water only 3 inches. When this was done the cage rotors did not impart sufficient velocity to the liquid. We then installed two flow inducers which are essentially floating canoes with impellers that rotate below the water surface so that they do not suck air.

The following is the designers description of these:

"The two hydraulic flow inducers installed at the sewage treatment plant at Glenwood, Minnesota are of the floating type which drive a submerged screw type propeller.

The hull is of welded steel construction about 16 feet long and 6 feet wide which has a deep, narrow nacelle shaped underwater portion which contains the drive machinery, and a wide, flat upper portion, most of which floats above water and provides floating stability.

The hull is fitted with a hatchway and removable cover, railing and deck fittings.

The drive consists of a 10 horsepower, four speed electric motor, electric speed controller, reduction gear, couplings, drive shaft which turns a 30 inch diameter propeller. Automatic ventilation and pumping means and alarm system are provided.

Each unit is held in operating position at the centerline of a straight portion of the oxidation channel securred by taught cables attached to deck fittings on the hull and to anchors on the side of the channel."

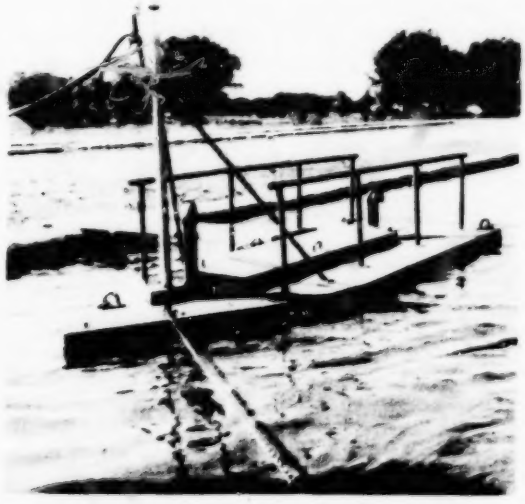

PLATE I

The flow inducer.

The following table shows the water velocities inducted by the various speeds of the flow inducer propeller and various combinations of them with the cage rotors in operation.

Table I

Liquid velocity in the channel with various combinations of propeller speeds in the flow inducers with and without the operation of the cage rotors.

Condition		Liquid velocity feet/sec.	
Flow Inducers	Cage Rotors	Near Liquid Surface	Near bottom of channel
Speed 4	off	1.17	1.10
Speed 3	off	0.70	0.60
Speed 2	off	0.60	0.40
Speed 1	off	0.40	0.00
Speed 2	Both on	1.35	1.23
Speed 2	One on-one off	1.10	0.93
Off	One on-one off	0.70	0.60

The raw sewage pumped from the wet well enters the aeration channel in front of one pair of cage rotors, so that the raw sewage is immediately subjected to some aeration. A small housing is provided over the cage rotors to prevent freezing or ice formation in the winter time. This house also extends over the weir box where the raw sewage enters from the pumps and where the raw sewage automatic sampler is installed.

PLATE 2
Raw sewage influent

PLATE 3
Location of cage rotors

The overflow from the aeration channel is conveyed to the final settling tank through a 12 inch pipe that can be rotated. The effluent enters the pipe through a longitudinal slot and as the pipe is turned the level of the slot changes and in turn the level of the liquid in the channel. The liquid in the channel can thus be varied from a submergenance of the paddles in the cage rotors from three to nine inches.

The final settling tank is 12 feet wide and 40 feet long with a water depth of 7 to 8 feet. At the outlet end there are provided 72 linear feet of weirs. This tank is provided with a sludge removal and skimming mechanism that scrapes the solids into a pit at the inlet end of the tank and from here is continuously removed by a sludge return pump and is normally pumped back into the aeration channel. The skimmings are returned to the raw sewage or are pumped into the truck that hauls sludge. When solids have accumulated to an optimum point in the channel the solids can be removed from the system by pumping them into a tank truck for haulage onto land.

PLATE 4

Sludge being sprayed on grass lands - municipal airport

The effluent from the final tank passes through a chlorination chamber providing for a detention period of approximately 30 minutes. Before the plant was built at Glenwood measurements were made of the flow of sewage. These studies indicated that the normal flow at Glenwood was 240,000 gallons per day. As a result the plant was designed for this normal flow but with a peak flow of 400,000 gallons. Shortly after the plant was put into operation, it was discovered that there had been a considerable increase in the amount of infiltration into the sanitary sewer system so that the flow was much greater than had been anticipated - in fact the first year after we had our laboratory staff installed, the flow of raw sewage varied from 600,000 to a million gallons per day. The City engaged an engineer to make a survey of the sanitary sewer system to discover where the leaks were coming from and he found one break in the storm water sewer system that emptied directly into the sanitary sewer system and when this was corrected, the flow was reduced 75 gallons per minute, but even after this was done, there still remained excessive infiltration and the flow remained considerably above 400,000 gallons per day. It was discovered on further

studies of the sanitary sewer system that a good portion of this sewer system was below the water level in the lake and infiltration was coming from the lake. This was aggravated by a clogging of the outlet channel from the lake, causing the lake level to rise two feet above normal. When this outlet had been cleared, the lake level gradually dropped and the flow was reduced to between 350,000 and 450,000 gallons per day. Even with this flow we found that the final settling tank was not large enough to remove all of the fine suspended solids that came over from the aeration channel and as a result the BODs and the suspended solids of the effluent were higher than we felt the process was capable of producing. To correct this, the city constructed a stabilization pond with a capacity of approximately 200,000 gallons, which gave a detention period of approximately 12 hours for the effluent flow. A drain with a valve was provided at the inlet end of this pond that was connected to the sanitary sewer system so that when necessary the pond could be emptied into the sanitary sewer system and passed through the plant. Provision was made so that the liquid coming from the chlorination chambers could flow into this stabilization pond or could be diverted directly to the creek so that when the pond has to be emptied the water can then be diverted directly to the creek from the chlorination chamber. By draining the pond slowly over a period of several days it could be emptied without unduly increasing the influent flow. It is anticipated this will be necessary once or twice a year.

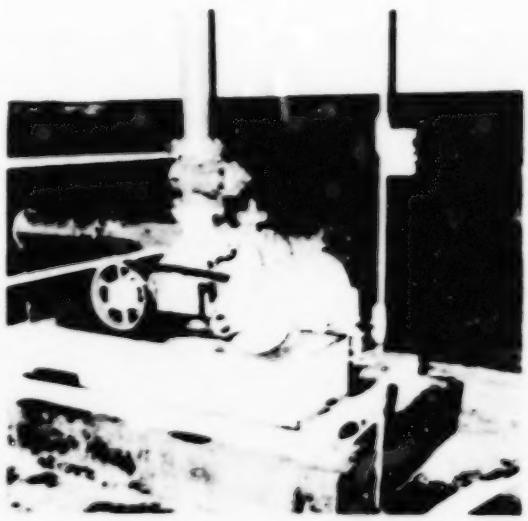

PLATE 5

Return Sludge Pump

When the sludge pump is returning sludge from the hopper of the settling tank back to the aeration channel it is set to deliver approximately 250 to 300 gallons per minute. When sludge has to be removed to the tank truck for haulage onto land the valve is cracked so that the flow is reduced to about 50 gallons per minute. This allows the removal of sludge from the bottom of the hopper at a higher density than what is obtained when the sludge is returned directly to the aeration channel.

To avoid settling of solids in the aeration channel it has been found necessary to maintain a velocity of liquid in the channel of approximately 1 foot per second. When the cage rotors are set to operate with their paddles at a water depth of from 5 to 9 inches this velocity is obtained without the use of the auxilliary flow inducers. However, when the level of liquid is only 3 inches they do not induce sufficient velocity to prevent settling of solids in the channel and at that time it is necessary to put into service the auxilliary flow inducers. This is also necessary when only one of the cage rotors is operating.

MATERIALS AND ANALYTICAL PROCEDURES

Composite samples were collected with a Lakeside Simplex samples placed in v notch weir boxes. Samples were collected and analyzed approximately 5 days per week, about 20 per month, exclusive of Saturdays, Sundays and holidays.

The flow as recorded on an integrated flow meter in the laboratory.

Analytical procedures followed standard methods except of organic and ammonia nitrogen. Here after digestion we determined the ammonia by the Phenol hypochlorite colormetric method, Russell (1944) using a Bosch & Lomb Mo80 spectrometer to read the intensity of the colors.

Dissolved oxygen in the channel and in the BOD bottles was determined by a Galvanic cell oxygen analyzer supplied by Precision Scientific Co. Each day the oxygen cell was standarized by comparison with

Jane Russell: The Phenol Hypochlorite Method for the Determination of Ammonia. J. Biol. Chem Vol.156:454 (1944)

a sample run by the Standard Winkler Method. Volatile solids were determined by ashing the solids in aluminum weighing dishes that were subjected to a temperature of 575°C. in the incinerator oven.

Liquid flow velocities in the channel was measured with a Gurley instrument.

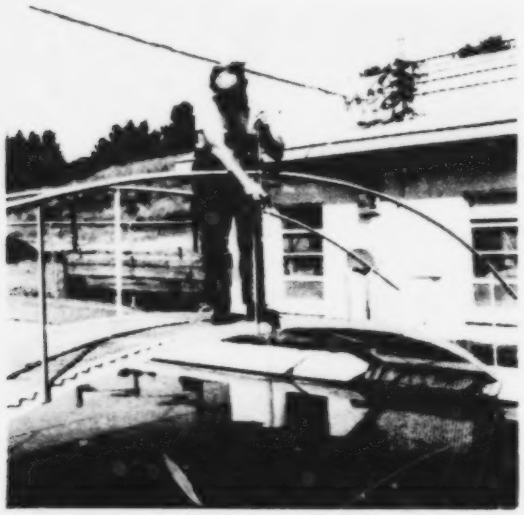

PLATE 6

The plant operator measuring the liquid velocity in channel

RESULTS

The analytical data are divided into two sections. The first July 1967 - June 1968, obtained before the construction of the stabilization pond, and the second July 1968 to June 15, 1969 after the stabilization pond was put to use. The results obtained prior to 1967 are not included due to the very heavy flow that occurred during that period.

During the first period the flow of sewage was generally too high for proper settling in the final tank, and as a result the removal of BOD and settleable solids was below the capability of the process. Much better results were experienced during the second period.

Table II and Figures 1,2,3 and 4 show the monthly averages of the BOD's and suspended solids. Table III and Figure 5 and 6 show the monthly averages of nitrate N in the effluent and the removals of total nitrogen.

An examination of these data indicate that there is an inverse correlation between the nitrate content in the effluent and the percentage of nitrogen removed.

The removal of phosphate in the plant is shown in Table IV and Figure 7 and 8 and is not considered satisfactory. We therefore instituted some laboratory studies to determine the amount of chemicals (aluminum sulfate or sodium aluminate) that are needed to reduce the Phosphate content to 0.5 ppm or less of P. To do this we treated samples of effluent or the mixed liquid from the aeration channel with varying amounts of these chemicals. This was done in the laboratory by adding gradually with a micropump a solution of the chemical to 1,000 or 500 of the liquid in a glass beaker. The P content before and after the treatment was determined and we compared the ratio of the moles of aluminum added to the moles of Phosphorous in the original liquid to the amount of P remaining in the liquid following settling. The results are given in Tables V, VI, VII and Figure 9.

In Table VIII are listed the monthly averages of the COD values during 1968-1969 in the raw sewage and effluent and the difference between these two which show the amount of COD removed by the system.

Table VIII show the number of loads of sludge that was hauled out from July 1968 to June 15, 1969. Each load carried 1100 gallons and the average solid content was 1.5%.

Table II

BOD AND SUSPENDED SOLIDS MONTHLY AVERAGES

1967-1968

Month	BOD			Suspended solids			Flow
	Raw	Eff.	%Red	Raw	Eff.	%Red	1000 g
July	146	9.3	94	114	22	80	384
Aug.	151	12	92	148	16	89	350
Sept.	137	8	94	113	18	84	312
Oct.	102	17	83	89	39	56	225
Nov.	121	12	90	84	30	64	324
Dec.	139	27	80	86	33	61	333
Jan.	125	34	72	74	43	42	362
Feb.	122	25	87	86	46	46	360
March	98	23	77	76	38	50	360
April	70	33	53	53	112	0	553
May	86	26	70	66	63	3.2	500
June	79	14	82	81	40	50	505
Average	116	20	83	89	41	54	389

1968-1969

July	102	3.6	96	90	3.9	95	417
Aug.	83	2.8	97	114	4.2	96	333
Sept.	93	2.5	97	100	3.3	97	345
Oct.	69	1.1	98	78	2.7	97	373
Nov.	73	2.9	97	77	2.5	97	376
Dec.	61	3.0	95	77	3.9	95	352
Jan.	97	7.6	92	75	6.2	92	349
Feb.	90	11.0	88	77	5.7	92	371
March	103	13.0	88	62	13.0	79	500
April	48	10.0	79	40	10.0	75	885
May	53	14.0	70	46	11.0	76	800
June	62	8.0	87	40	9.6	79	531
Average	78	6.6	92	73	6.2	91	476

Table III

NITRATE N IN EFFLUENT AND TOTAL NITROGEN

1967-1968

Month	Nitrate N in Eff. ppm.	Total N ppm Raw	Eff.	%Red
July	7.2	19.4	8.8	55
Aug.	4.0	17.3	5.1	71
Sept.	4.9	22.3	6.8	70
Oct.	9.3	21.6	11.0	49
Nov.	15.7	23.1	17.1	26
Dec.	15.0	25.5	18.4	28
Jan.	6.0	25.3	12.2	52
Feb.	4.5	28.2	9.1	68
March	5.5	21.7	9.8	55
April	8.7	17.4	13.4	23
May	8.0	18.8	11.4	39
June	3.6	14.1	5.3	62
Average	7.5	21.2	10.7	50

1968-1969

July	3.8	16.2	4.3	73
Aug.	6.4	17.5	7.2	58
Sept.	4.2	19.8	6.2	69
Oct.	4.8	19.0	6.4	66
Nov.	6.4	23.1	7.9	66
Dec.	4.0	22.0	8.1	63
Jan.	5.9	23.7	12.0	50
Feb.	4.9	24.3	9.8	60
March	6.8	17.8	12.5	29
April	6.8	16.7	10.5	32
May	4.9	14.2	7.9	42
June	0.8	16.1	4.0	72
Average	5.0	19.2	8.1	57

Table IV

Phosphate Content
as ppm of P

MONTH	RAW	EFFLUENT	%REDUCTION
	1967-1968		
July	7.0	6.0	14
Aug.	8.8	6.1	31
Sept.	8.0	6.4	20
Oct.	9.2	8.2	11
Nov.	8.0	5.8	28
Dec.	7.8	8.1	9
Jan.	7.5	6.6	12
Feb.	7.4	6.8	8
March	7.0	6.6	6
April	4.5	6.3	0
May	6.0	5.2	13
June	6.2	4.9	21
Average	7.3	6.5	11.0
	1968-1969		
July	8.2	5.9	28
Aug.	7.7	6.2	27
Sept.	7.7	5.9	23
Oct.	6.9	5.3	23
Nov.	7.8	6.1	22
Dec.	6.8	5.9	16
Jan.	6.9	5.4	22
Feb.	7.4	6.1	18
March	5.7	5.4	6
April	3.3	3.1	7
May	4.2	3.4	20
June	5.3	4.6	13
Average	6.5	5.3	18.5

Table V

Treatment of Effluent with Aluminum Sulfate for Removal of Phosphate

Exp. No.	mMoles P/l Present	mMoles AL/l added	Ratio II/I	ppm.P remaining
1.	.045	.26	5.8	.03
2.	.045	.114	2.5	.35
3.	.107	.26	2.4	.36
4.	.107	.208	2.0	.75
5.	.107	.26	2.4	.36
6.	.107	.208	2.0	.58
7.	.107	.166	1.6	.75
8.	.107	.208	2.0	.58
9.	.107	.166	1.6	1.30
10.	.107	.166	1.6	.91
11.	.053	.052	1.0	1.01
12.	.053	.052	1.0	1.01
13.	.053	.052	1.0	1.01
14.	.053	.052	1.0	1.17
15.	.053	.052	1.0	1.01
16.	.107	.052	.5	2.76
17.	.107	.052	.5	2.79
18.	.052	.052	.5	2.73
19.	.16	.52	3.2	0.049
20.	.26	.126	1.6	.55
21.	.312	.312	2.0	.29
22.	.12	.52	4.3	.23
23.	.12	.26	2.2	.78
24.	.12	.52	4.3	.049

Table VI

Treatment of mixed liquor with aluminum sulfate for removal of phosphate

	I	II		
Exp. No.	mMoles of P/l present	mMoles of AL/l added	Ratio II/I	ppmP remaining
1.	.197	.129	.66	5.14
2.	.197	.258	1.31	4.28
3.	.197	.387	1.96	3.57
4.	.197	.516	2.61	3.25
5.	.197	.645	3.27	2.66
6.	.197	.774	3.96	2.34
7.	.197	.903	4.56	2.30
8.	.197	1.032	5.23	1.95
9.	.197	1.161	5.9	1.46
10.	.200	.516	2.58	2.7
11.	.177	.774	4.35	2.79

Table VII

Treatment of Effluent with Sodium Aluminate for removal of Phosphate

	I	II		
Exp.No.	mMoles of P/l present	mMoles AL/l added	Ratio II/I	ppmP remaining
1.	.155	.519	3.3	.55
2.	.29	.519	1.78	4.36
3.	.29	1.035	3.6	2.02
4.	.29	.519	1.78	4.29
5.	.29	1.557	5.5	1.40
6.	.122	.519	4.4	.52
7.	.122	.570	4.7	.48

Table VIII

MONTH	C.O.D.'s MONTHLY AVERAGES				LOADS OF SLUDGE HAULED		FLOW
	Raw	Eff.	Retained in ditch		Each 1100 Gal.**		Million Gal/Day
July	220	46	174		0		.417
Aug.	245	34	211		26		.333
Sept.	220	35	185		60		.345
Oct.	206	37	169		46		.373
Nov.	244	34	210		42		.376
Dec.	222	45	177		25		.352
Jan.	223	52	171		0		.349
Feb.	186	44	142		0		.371
March	188	54	124		47		.500
April	128	53	75		32		.885
May	232	52	180		75		.800
June *	180	54	126		75		.531
Average	208	45	165	Total	428	Avg.	.476

*Only 15 days in June **Sludge hauled 1.5% organic solids

Pounds solids imput	.476 x 8.3 x 163	=	225,393
Solids hauled 428 x 1100 x 8.3 x .015		=	58,614
Solids oxidized in ditch		=	166,777
Percent oxidized 166/225		=	74

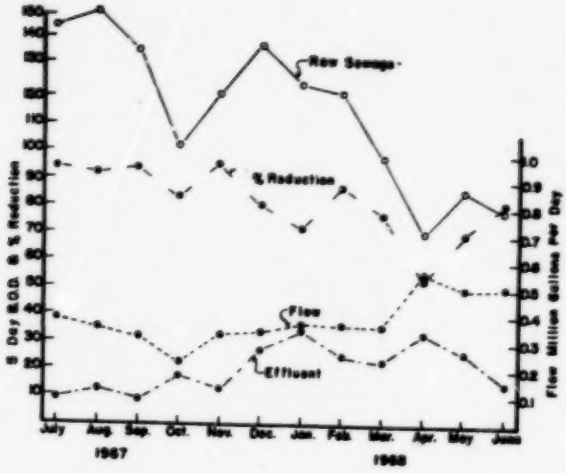

Fig.1

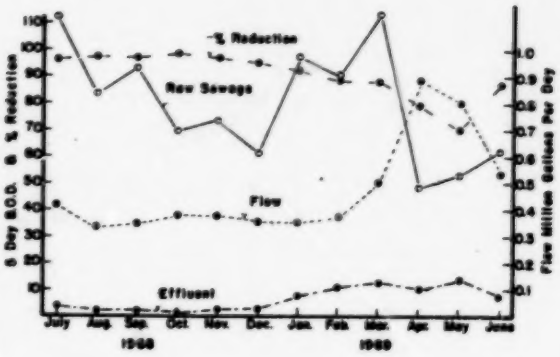

Fig.2

B.O.D.'s MONTHLY AVERAGES

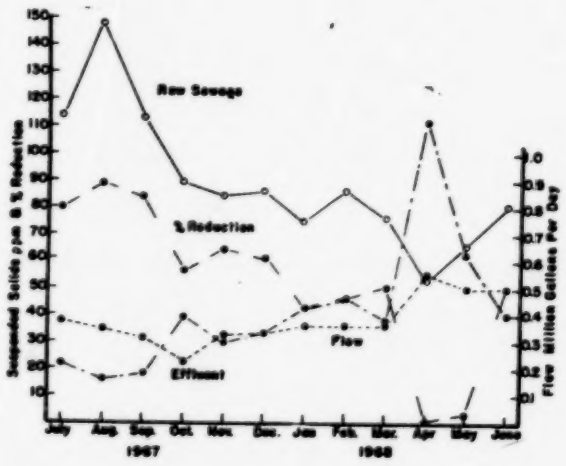

Fig.3

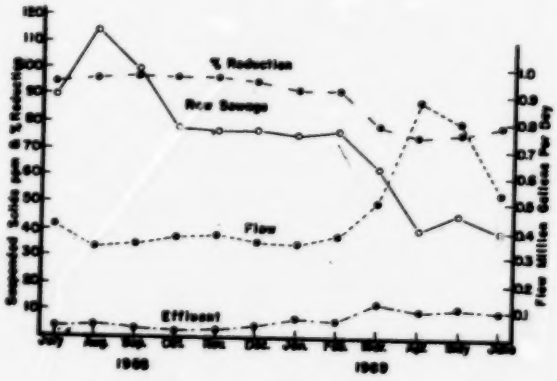

Fig.4

SUSPENDED SOLIDS MONTHLY AVERAGES

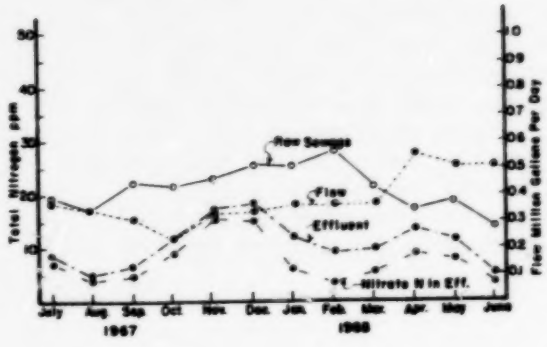

Fig.5

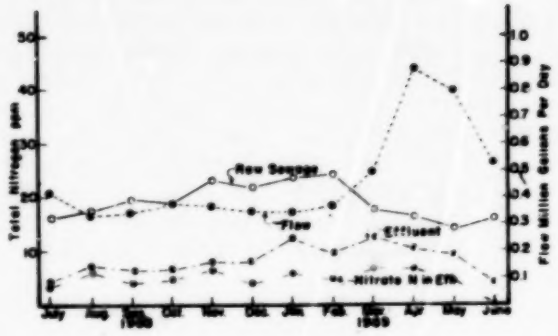

Fig.6

TOTAL NITROGEN MONTHLY AVERAGES

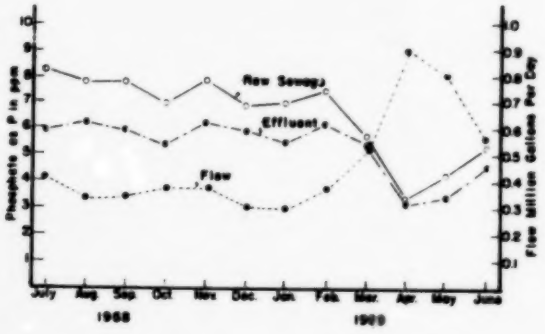

Fig.7

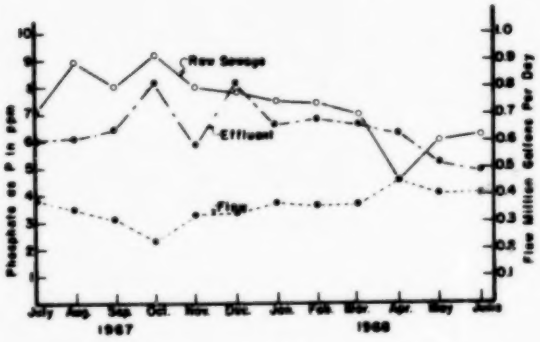

Fig.8

PHOSPHATE CONTENT MONTHLY AVERAGES

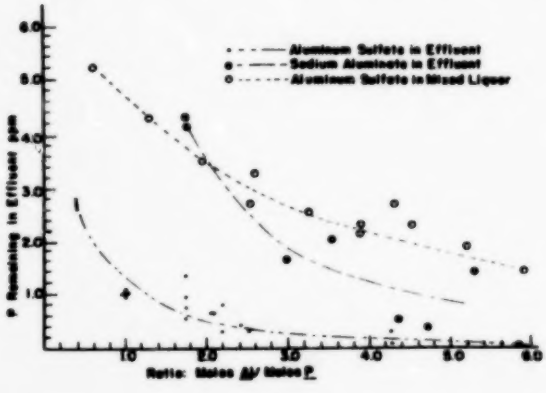

Fig.9
REMOVAL OF PHOSPHATE
WITH CHEMICALS

In Table IX are listed the daily average KWH's used for 10 months from September 1968 to June 1969. This includes the electrical power used for the pumping of the raw sewage into the aeration channel, that used for the pumping of the return sludge, the electricity used for the operation of the laboratory equipment and the lights in that building, the lights used under the cover of the final tank in the winter months to keep the liquid in the tank from freezing at the surface, and the electrical power used to operate the motors on the equipment in the aeration channel.

Table IX

Month	Daily average KWH's used
September	445
October	583
November	552
December	597
January	628
February	626
March	635
April	659
May	534
June	493
Average	575

DISCUSSION

It is evident from Table II and Figures 1,2,3 and 4 that there was a marked improvement in the percentage removal of BOD and suspended solids in a period July 1968 to June 1969 over the corresponding period from July 1967 to June 1968 and this is due to the better settling obtained in the stabilization pond over that accomplished in the settling tank only. For the earlier period the average reduction in BOD was 83% while the second period was 92%. For the suspended solids the average removal for the period 1967-1968 was 54% while the corresponding period of 1968-1969 was 91%. The lower percentage reductions obtained during the months of March, April and May and part of June is due to the heavy flow caused by the spring runoff and rain. It has been noted that during this period the flows increased above 400,000 gallons up to as high as 900,000 gallons per day.

It is obvious from the above that if one is to design a Pasveer process, care must be exercised in the design of the final settling tank. Good final settling is essential for this process. In designing rectangular tanks, engineers very often base the size of the tank on a vertical rise of liquid based upon the entire surface of the tank. At Glenwood the tank is 12 feet wide and 40 feet long making an area of 480 square feet. With the flow of 400,000 gallons per day this makes a vertical rise of 833 gallons per day per square foot surface. Actually the liquid does not rise vertically over the entire surface of the tank but only in the weir area. In the tank at Glenwood the weir area is 12 x 6 feet making an area of 72 square feet. With a flow of 400,000 gallons per day this represents a vertical rise in this area of 5555 gallons per square foot per day. Obviously this is a very high figure. We are not in a position to state at this time what the vertical rise should be in the area of the weirs, but it certainly should be a figure less than 5000.

An examination of Table III and Figures 5 and 6, suggest that the percent removal of nitrogen is related to the amount of nitrate in the effluent. This is particularly noticeable during the months of October, November and December. For these three months during 1967 the average amount of nitrate N in the effluent was 13.3 ppm and the average removal of total nitrogen was 34%. During the corresponding months of 1968 the average amount of nitrate N in the effluent was 5.1 ppm and the average removal of total nitrogen was 65%. In 1967 we did not have the flow inducers in operation during these three months because they were not installed until

January of 1968. In the three corresponding months of 1968 the flow inducers were in operation. Before we installed the flow inducers we had to operate the cage rotors with a 6 inch immersion of the blades in order to get enough velocity for 1 foot per second as needed to prevent settling of solids in the channel and with this amount of immersion of the blades during the cold weather of October, November and December the dissolved oxygen content went fairly high and that accounts for the high amount of nitrate. Once the flow inducers had been installed we could operate with a lower water level in the channel so as to have the blades immersed in the liquid only 3 inches to limit the aeration. We could shut off one of the aerators at intervals to again limit the amount of oxygen introduced. A further indication of the affect of the flow inducers can be seen in the months of January and February 1968; this is immediately after the installation of the flow inducers and during these two months, even though the weather remained cold, the average amount of nitrate N in the effluent was 5.2 ppm and the average amount of removal of total nitrogen was 60%. This is a considerable improvement over the results obtained during the three preceding months of October, November and December 1967. And for comparison it is to be noticed that for 1969 the average amount of nitrate N in the effluent for January and February was 5.4 ppm and the average removal of total nitrogen was 55%. These results emphasize the importance of having independent control of aeration and velocity, particularly if one is treating a relatively weak sewage where the operation of all of the cage rotors are essential in order to maintain the proper velocity of the liquid in the channel. If one is treating a strong sewage then more cage rotors are necessary for a given volume of liquid and thus one could control the degree of aeration by shutting off some of the cage rotors and still have enough left operating to maintain a velocity. If one is treating a weak sewage on the other hand, it will be necessary to have independent flow inducers that can maintain the proper velocity of the liquid without introducing air.

A further illustration of the correlation between the amount of nitrate N in the effluent and the percent removal of total nitrogen brought out in Table X in which we have segregated the results in two categories; first those during 1968-1969 in which the nitrate N in the effluent varied between 0 and 3 ppm - compared this with the days in which the nitrate N in the effluent varied from 3.1 and up. The data in Table X have been subjected to statistical analysis and it shows that there is a significant inverse correlation between the percent removal of total nitrogen and the amount of nitrate in the effluent. When the nitrate N in the efflu-

ent was maintained between 0 and 3 ppm the percent removal was 72% while when it was allowed to rise above 3 ppm it averaged 50%. The amount of nitrogen in the effluent can be controlled by controlling the aeration. We have found that if we wished to keep the nitrate N in the effluent below 3 ppm then we should not allow the dissolved oxygen to rise above 1.5 ppm. In fact if we could control the dissolved oxygen in the channel between 0.1 and 1.5 ppm we would have a much better removal of total nitrogen than if we allowed it to rise above that value. We found it difficult to have the operators control the process so that the amount of dissolved oxygen remained in this lower limit, which indicates that it might be desirable in plants of this kind to have automatic control of the aeration by having auxilliary aerators that can be activated by a recording oxygen electrode.

Table X

Nitrate N in Effluent 3.0 or less
vs.
% Reduction in Total Nitrogen

Nitrate N	%Reduction	Nitrate N	%Reduction
.07	82.5	.4	89
.07	54	.15	66
.07	48	.15	73
.08	68	1.9	66
3.0	74	.9	73
2.5	81	.4	82
2.4	65	.15	66
1.05	73	.22	50
1.5	85	1.2	68
3.0	83	.7	62
0.5	76	2.8	66
.25	88	.7	70
.40	83	.1	79
2.4	79	.4	66
2.4	76	2.6	63
0.5	74	.45	69
0.3	72	.25	83
0.6	80	1.7	77
2.1	86	.8	74
2.7	74	2.9	55
.65	60	2.6	78
		1.7	70
	Mean	1.16	72 ± 4.0

Table X (Continued)

Nitrate N in Effluent 3.1 or higher
vs:
%Reduction in Total Nitrogen
1968-1969

NitrateN	%Red.	NitrateN	%Red	Nitrate N	%Red
3.2	49	7.9	51	5.6	37
5.3	59	4.8	66	3.1	55
5.6	65	3.1	78	3.8	52
4.1	67	3.7	76	6.1	44
3.4	35	7.0	69	8.8	13
9.2	33	5.2	48	9.2	34
7.2	59	6.2	53	9.2	25
5.6	54	7.0	54	9.2	12
5.2	55	7.8	58	5.4	68
4.0	65	5.7	70	3.6	63
3.2	76	7.6	41	3.3	66
4.9	67	7.1	44	6.4	57
6.0	60	5.3	62	6.6	40
6.3	75	5.0	65	6.8	48
6.2	61	5.3	51	6.0	30
6.9	60	8.0	52	5.1	59
6.5	68	8.6	61	3.8	55
7.2	59	10.0	40	3.7	36
9.0	59	9.9	55	4.8	42
5.5	64	8.7	53	6.8	29
8.7	48	6.8	80	5.4	56
7.2	67	4.0	46	10.3	30
4.6	74	6.2	47	8.7	48
5.9	76	7.0	59	7.0	55
8.0	59	7.2	45	9.4	39
7.8	38	6.5	55	3.3	66
8.2	55	9.0	0	3.6	69
7.4	61	9.2	14	4.0	71
3.4	68	8.4	20	4.7	42
5.1	66	6.8	28	3.4	59
6.2	62	7.8	22	6.0	47
6.4	57	8.7	20	5.7	38
7.0	30	9.0	22	6.4	44
5.6	58	9.4	43	3.7	52
8.1	50	9.1	25	5.2	53
7.1	54	7.8	41	4.9	34
5.2	57	6.6	43	3.9	34
3.7	54	6.9	27	9.9	0
8.5	59	7.0	42	10.5	12
				6.38	50 ± 3.2

One may inquire as to what happens to the nitrogen if the nitrate is kept low so it does not escape in the effluent as nitrate. We have observed that if the dissolved oxygen is above 0.1 there is very little ammonia escaping in the effluent. On two different occasions we attempted to determine the nitrogen balance in the system. For this purpose we took many samples from the aeration channel on a Monday morning and determined the amount of nitrogen in the composite sample of the channel. During the next five days we kept accurate record of the amount of nitrogen brought into the plant with the raw sewage. We also kept an accurate record of the amount of nitrogen that escaped in the effluent. During this period we did not haul away any sludge from the system. At the end of the week we again took many samples from the channel to get another composite sample and determined the amount of nitrogen in this sample. From these data we could calculate the amount of nitrogen in the system at the beginning of the experiment, the amount brought in with the raw sewage, the amount lost in the effluent, and the amount remaining in the channel at the end of the experiment. In one of these experiments we calculated that almost 80% of the nitrogen brought into the plant that did not escape into the effluent was lost through denitrification. The second time we ran the experiment we calculated that 70% of the nitrogen was lost through denitrification. We are not sure of the accuracy of these data because of possible errors in sampling, but the data do indicate that much of the nitrogen can be lost through denitrification if the dissolved oxygen in the aeration channel is kept low.

Most bacteriologists tend to agree that denitrification occurs only under anaerobic conditions. If this is true, then how can we explain the large amount of denitrification occurring in this channel. If we maintain the dissolved oxygen at a very low level it is probable that we do not have a uniform micro environment but that inside particles of sludge conditions may indeed be anaerobic and in this area denitrification could take place. If we maintain the dissolved oxygen at a high level such anaerobic conditions would not exist in the micro environment and therefore we would get nitrate formation rather than denitrification.

These observations confirm findings reported in the experiments we conducted at the University of Illinois and reported in an article by Irgens and Halvorson. (1965)[2]

[2] Roar L. Irgens and H.O. Halvorson, Removal of Plant Nutrients by Means of Aerobic Stabilization of Sludge- Applied Microbiology, 13 373-386, 1965.

Examination of Table IV and Figures 7 and 8 show that the removal of phosphate was rather unsatisfactory and there was no significant difference between the amount of removal during the period 1967-1968 and 1968-1969. In preliminary experiments that we had conducted at the University of Illinois we found that we could remove a very large percentage of the phosphate when we attempted to stabilize primary sludge by an aerobic oxidation method. It is probable that we could have had much higher removals of phosphates if we had been dealing with a stronger sewage. The only way phosphate can be removed by biological methods is to have the micro-organisms tie up the phosphate in their protoplasm. When one is dealing with a strong sewage there will be more microbial growth and more microbial protoplasms produced and therefore more phosphate will be tied up. But in the weak sewage such as we have at Glenwood the amount of bacterial growth is limited.

We were desirous of determining the amount of organic matter that was oxidized in the channel, but the inadequacy of analytical methods does not permit us to do this very accurately. We cannot rely upon volatile solids determination to do this because during ashing one looses weight from inorganic substances such as carbonates and bicarbonates as well as from the combustion of the organic matter. We have however attempted to make such estimates on the assumption that the loss of COD represents loss of organic matter pound for pound. This will be true if one does not deal with sewage that contains considerable amounts of fats and lipids. To this end we show in Table VIII the monthly averages of COD's for the period July 1968 to June 15, 1969, and in Table VIII the number of loads of sludge that was hauled out in 1968-1969. The % solids in the hauled out sludge averaged 1.5%. From the data in this table we estimate that about 74% of the organic matter coming in with the raw sewage is oxidized by the micro-organisms.

One of the primary objectives of the demonstration plant at Glenwood was to see whether or not a channel aeration process would reduce the amount of algae in the lake. When we presented our proposal for research funds we had asked for sufficient funds so that we could also make a study of the algae content in the lake but this portion of the request was not granted. We therefore have not been able to get any quantitative data on the lake and therefore we have had to rely upon people's comments and our own general observations as to whether or not there has been any change in the algae growth in the lake during the period of this study. We have gained a general impression from various individuals that there

has been less algae in the lake in these last few years than was present for several years previous, and our own personal observations indicate that at least in the area of the lake near the effluent of the creek that carries the effluent from the sewage treatment plant, there is considerably less algae growth than there was in previous years. It will have to remain for future studies to verify these observations.

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